

α Anions. VII. Direct Oxidation of Enolate Anions to 2-Hydroperoxy- and 2-Hydroxycarboxylic Acids and Esters¹

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2-Hydroperoxy acids were obtained by direct low-temperature oxygenation of enolate dianions of straight-chain and branched-chain aliphatic carboxylic acids. Esters of 2-hydroperoxy acids were similarly obtained from ester enolate anions or by diazomethane reaction with 2-hydroperoxy acids. Alternatively, 2-hydroxy acids are formed directly and nearly quantitatively by dianion oxygenation at ambient temperatures. Stabilities, decompositions, and products of decomposition of the hydroperoxy acids and their esters are described.

Although 2-hydroperoxy esters of aliphatic³ and araliphatic⁴ acids were prepared a decade ago, attempts to derive the parent 2-hydroperoxycarboxylic acids through hydrolysis of the 2-hydroperoxycarboxylic esters^{5,6} or by free-radical autoxidation of fatty acids were ineffective.⁷ In the course of our studies on enolate dianions,^{8a} we indicated the reactivity of the dianions to oxygen and subsequently presented the reaction as a route to 2-hydroperoxy- and 2-hydroxycarboxylic acids.¹ The present paper describes the details of the oxygenation reaction and further provides a facile preparation of 2-hydroperoxycarboxylic esters which has advantages in scope and convenience over those pre-

viously reported.^{3,4} The decomposition of several hydroperoxycarboxylic acids and esters were also examined.

Simultaneously with our presentation of this work,¹ Adam and Liu⁵ reported two methods for deriving 2-hydroperoxy acids. The photodecarboxylation of an ether solution of di-*n*-butylmalonoyl peroxide in the presence of hydrogen peroxide gave 2-butyl-2-hydroperoxyhexanoic acid, which resisted purification. Their more successful alternate method employed the enolate dianion of 3,3-dimethylbutyric acid, which on silylation, oxygenation, and hydrolysis in methanol gave the desired 2-hydroperoxy acid. Although quantitative yields of hydroperoxy acid were reported for

Table I
Preparation of 2-Hydroperoxycarboxylic Acids

Starting acid	Registry no.	% oxidation ^a	% 2-OOH ^b	Registry no.	% yield ^c	Mp, °C
Octanoic	124-07-2	86	50	53705-92-3	30	67-68
Tetradecanoic	544-63-8	93	50	53705-94-5	30	89-90
2-Methylpentanoic	97-61-0	92	72		<i>d</i>	Liquid
2-Methyldecanoic	24323-23-7	65	55	53705-99-0	43	45-46
2-Ethyldecanoic	2874-76-2	89	70		<i>d</i>	Liquid
2-Methyltetradecanoic	6683-71-2	88	68	53705-97-8	66	57-58
2-Ethyltetradecanoic	25354-93-2	93	78	53705-98-9	67	Liquid
2-Propyltetradecanoic	53705-91-2	90	75	53705-96-7	65	Liquid
2-Heptyldecanoic	53705-90-1	93	30		<i>e</i>	
<i>cis</i> - Δ^9 -Octadecenoic (oleic)	112-80-1	98	30		<i>e</i>	
<i>trans</i> - Δ^9 -Octadecenoic (elaidic)	112-79-8	98	45	56363-64-5	11	79-80
<i>trans</i> -3-Hexenoic	1577-18-0	96	49		<i>e</i>	
Phenylacetic	103-82-2	89	0 ^f			

^a Percent oxidation (total of hydroperoxy and hydroxy acid) determined by GLC analysis of esterified crude product. ^b Percent hydroperoxide determined by iodometric analysis of the crude product. ^c Percent yield based on isolated pure product. ^d Pure product was not isolated. ^e Hydroperoxy acid was unstable and decomposed prior to and during efforts at purification. ^f Products were benzaldehyde (60%), 2-hydroxyphenylacetic acid (25%), and benzoic acid (4%).

their given example, the scope of reactions was not examined for general utility. Their method also introduced the additional steps of silylation and methanolysis.

The direct oxygenation of dianions to 2-hydroperoxy acids is generally accompanied by formation of 2-hydroxy acids as side products. Moersch and Zwiesler⁹ recently described the preparation of the latter compounds by this route, but failed to observe formation of the hydroperoxy acids. However, we have observed that either oxygenated derivative may be substantially obtained by appropriate adjustments in procedure. The present direct preparation of 2-hydroxycarboxylic acids is notably superior for branched-chain species¹⁰ that formerly became available only through low-yield multistep syntheses.^{10,11,12}

Experimental Section

Materials. Dry, oxygen-free diethyl ether and tetrahydrofuran (THF) were each obtained by distillation from sodium and benzophenone under nitrogen. Hexamethylphosphoramide (HMPA) was distilled at reduced pressure from sodium hydride and stored under nitrogen. *n*-Butyllithium (1.6 M in hexane solution) was obtained from Foote Mineral Co.¹³ Diisopropylamine was distilled over calcium hydride and maintained under nitrogen.

Analytical Procedures. Conversions of carboxylic acids and esters to hydroperoxide derivatives were determined by a combination of iodometric and GLC analyses. Hydroperoxide contents of the product mixture and purity of isolated compounds were determined by a standard iodometric method.¹⁴ GLC analyses were obtained on esters that were prepared by reaction of carboxylic acids and derivatives with diazomethane. Analytical GLC was performed with an F & M Model 5750 gas chromatograph using 25% DEGA-2% phosphoric acid as column substrate. Esters of 2-hydroperoxy acids were determined from decomposition products thermally generated in the injection port (180°) and resolved on column at temperatures ranging from 150° for methyl 2-hydroperoxyoctanoate to 180° for methyl 2-hydroperoxytetradecanoate. Methyl 2-hydroxyalkanoates were also determined by GLC. Nuclear magnetic resonance spectra were recorded on a Jeolco C-60H NMR spectrometer. Infrared spectra were recorded on a Perkin-Elmer 457 grating spectrophotometer. Physical constants of the hydroperoxy acids, hydroperoxy esters, and hydroxy acids are listed in Tables I, II, and IV, respectively.

Representative Oxygenations. The following typical preparations of 2-hydroperoxy acids and esters and 2-hydroxy acids illustrate the small variation in procedure that applies to each homologous class.

I. Preparation of 2-Hydroperoxycarboxylic Acids. A. 2-Hydroperoxytetradecanoic Acid. Anhydrous THF (150 ml) and diisopropylamine (10.1 ml, 77.3 mmol) were added to a dry flask

flushed with nitrogen and cooled to -30°. *n*-Butyllithium (48.7 ml, 77.3 mmol) was added followed by tetradecanoic acid (8.0 g, 35 mmol) in THF (25 ml) and HMPA (6.33 ml, 35 mmol) while maintaining the temperature at -30°. Dianion formation was completed by heating the solution to 50° for 30 min and then cooling to room temperature. The dianion solution was added dropwise over a period of 1-2 hr to oxygen-saturated diethyl ether (150 ml) at -75°. The addition was made with a dropping funnel bearing an elongated stem with the tip immersed below the ether surface. The reaction mixture was acidified with dilute acid in the cold, the water layer was separated and extracted with ether, the combined ether layers were dried over sodium sulfate, and the products were recovered at ambient temperature by rotary evaporation. Iodometric analysis in conjunction with GLC analysis indicated 7% unreacted tetradecanoic acid, 50% 2-hydroperoxytetradecanoic acid, and 43% 2-hydroxytetradecanoic acid. Pure 2-hydroperoxytetradecanoic acid (30% yield, mp 89-90°) was obtained by crystallization from hot hexane upon cooling to 25°.

Anal. Calcd for C₁₄H₂₈O₄: C, 64.62; H, 10.77. Found: C, 64.31; H, 10.77.

B. 2-Hydroperoxy-2-methyltetradecanoic Acid. Dry THF (150 ml) was distilled under nitrogen into a dry flask. Diisopropylamine (5.05 g, 50 mmol) was added and the contents cooled to -10°. *n*-Butyllithium (31.5 ml, 50 mmol) and 2-methyltetradecanoic acid (5.5 g, 22.7 mmol) dissolved in THF (25 ml) were added in sequence while maintaining the temperature below 0°. Dianion formation was completed by heating to 50° for 2 hr and then cooling the solution to ambient temperature. The dianion solution was added dropwise to oxygen-saturated diethyl ether over a period of 1-2 hr at -75° from a dropping funnel as described in A above. The mixture was acidified in the cold with dilute hydrochloric acid solution, extracted with ether, dried over anhydrous sodium sulfate, and rotary evaporated at reduced pressure and ambient temperature. Analysis of the crude product gave 12% unreacted carboxylic acid by GLC, 68% 2-hydroperoxy-2-methyltetradecanoic acid by iodometry, and 20% 2-hydroxy-2-methyltetradecanoic acid by difference. Purification of the titled peroxide (4.45 g, 66% yield) was attained by silicic acid chromatography using CH₂Cl₂-ether (1:1) as the eluting solvent mixture.

Anal. Calcd for C₁₅H₃₀O₄: C, 65.69; H, 10.95. Found: C, 65.74; H, 10.88.

C. 2-Hydroperoxyelaidic Acid. The preparation of the dianion and its subsequent oxygenation and product isolation was equivalent to that described in IA. Immediate crystallization of the crude product from pentane (5 ml/g) followed by subsequent crystallizations from pentane-ether (10:1) mixture (22 ml/g) at 5° yielded pure 2-hydroperoxyelaidic acid [11% yield; mp 79-80°; ir (CHCl₃) 965 (trans C=C), 1720 (C=O), 3510 cm⁻¹ (OH); NMR (Me₄Si, CDCl₃) δ 4.57 (t, 1, α CH), 5.85 (m, 2, trans C=C), 10.2 (s, 2, COOH and OOH)].

II. Preparation of 2-Hydroperoxy Esters. A. Methyl 2-Hydroperoxyoctanoate. Anhydrous THF (100 ml) and *N*-isopropyl-

Table II
Preparation of 2-Hydroperoxy Esters

Starting ester	Registry no.	% oxidation ^a	% 2-OOH ^b	Registry no.	% yield ^c	Mp, °C
Methyl octanoate	111-11-5	82	65	56363-66-7	55 (2) ^d (15) ^d	Liquid
Methyl octanoate ^e		30	23			
Methyl 2-hexylnonanoate	56363-65-6	99	78	56363-67-8	69	Liquid
<i>tert</i> -Butyl dodecanoate	7143-18-2	92	73	56363-68-9	61	41-41.5
Methyl oleate	112-62-9	72	61	35277-31-7	43	Liquid
Ethyl <i>trans</i> -3-hexenoate	26553-46-8	93	13	56363-69-0	<i>f</i>	

^a Percent oxidation (total hydroperoxy and hydroxy esters) determined by GLC of crude product. ^b Percent 2-hydroperoxide determined by iodometric analysis of crude product. ^c Percent yield determined by isolation of pure product. ^d Claisen condensation product. ^e Inverse addition of enolate solution to oxygen saturated ether solution. ^f Hydroperoxy ester unstable and decomposed prior to and during efforts at purification.

N-cyclohexylamine (3.76 ml, 20 mmol) were added to a dry flask and cooled to -75° . *n*-Butyllithium (20 mmol) and methyl octanoate (3.16 g, 20 mmol) in THF (50 ml) were added while the solution was maintained at approximately -75° , then stirred for an additional 15 min to complete enolate anion formation. HMPA (3.58 ml, 20 mmol) was added, stirring was continued for 15 min, and oxygen was bubbled into the solution for 1 hr. The solution was acidified and the product was isolated by ether extraction and evaporation as described in the foregoing illustrations. Analysis indicated 65% conversion to methyl 2-hydroperoxyoctanoate by iodometry, 18% unreacted methyl octanoate, and 2% Claisen condensation product by GLC, and 15% methyl 2-hydroxyoctanoate by difference. Purification of methyl 2-hydroperoxyoctanoate (1.60 g, 55% yield) was obtained by silicic acid chromatography: ir (film) 1735 (C=O), 3400 cm^{-1} (OH); NMR (Me_4Si , CCl_4) δ 3.8 (s, 3, OCH_3), 4.45 (t, 1, α CH), 9.78 (br s, 1, OOH).

B. Diazomethane Esterification of 2-Hydroperoxy Acids.

Methyl esters of the hydroperoxy acids described above were alternatively prepared by reaction with diazomethane. Reaction of diazomethane was specific with the carboxylic acid functionality and gave no evidence of attack at the hydroperoxide group.

1. **Methyl 2-Hydroperoxytetradecanoate:** ir (CCl_4) 1740 (C=O), 3480 cm^{-1} (OOH); NMR (Me_4Si , CCl_4) δ 3.78 (s, 3, OCH_3), 4.4 (t, 1, α CH), 10.25 (br s, 1, OOH).

2. **Methyl 2-Hydroperoxy-2-methyltetradecanoate:** ir (CCl_4) 1738 (C=O), 3475 cm^{-1} (OOH); NMR (Me_4Si , CCl_4) δ 1.43 (s, 3, α Me), 3.80 (s, 3, OCH_3), 8.96 (s, 1, OOH).

3. **Methyl 2-Hydroperoxyelaidate.** Anal. Calcd for $\text{C}_{19}\text{H}_{36}\text{O}_4$: C, 69.51; H, 10.98. Found: C, 69.11; H, 10.84.

III. Preparation of 2-Hydroxy Acids. A. 2-Hydroxyoctanoic Acid. The dianion of octanoic acid was prepared as described for tetradecanoic acid in IA. The reagents and quantities used were diisopropylamine (4.45 g, 44 mmol) in THF (100 ml), *n*-butyllithium (44 mmol), octanoic acid (2.88 g, 20 mmol) dissolved in THF (25 ml), and HMPA (3.6 ml, 20 mmol). Oxygen was bubbled directly into the dianion solution at room temperature for 30 min and the product isolated as described in IA for the hydroperoxy acid. The crude product consisted of 2% 2-hydroperoxyoctanoic acid by iodometry, 4% unreacted octanoic acid by GLC, and 94% 2-hydroxyoctanoic acid by GLC. Crystallization gave pure 2-hydroxyoctanoic acid (2.0 g, 63% yield, mp 70° , lit. 69.5°): ir (CHCl_3) 1720 (C=O), 3515 cm^{-1} (OH); NMR (Me_4Si , CCl_4) δ 4.2 (t, 1, α CH), 7.62 (br s, 1, OH).

Anal. Calcd for $\text{C}_8\text{H}_{16}\text{O}_3$: C, 60.00; H, 10.00. Found: C, 60.36; H, 10.16.

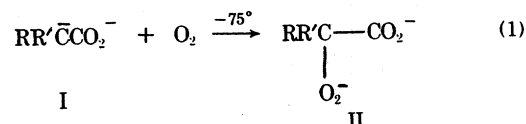
B. 2-Hydroxy-2-methylvaleric Acid. The dianion was prepared as described in IB with reagents and amounts as follows: diisopropylamine (9.55 g, 94.6 mmol) in THF (150 ml), *n*-butyllithium (94.6 mmol), and 2-methylvaleric acid (5 g, 43 mmol) in THF (25 ml). The solution was oxygenated by direct passage of oxygen at 25° for 30 min and the product isolated as described in previous examples. Analysis of the crude oily product indicated the presence of 12% 2-hydroperoxy-2-methylvaleric acid and ~1% 2-methylvaleric acid. Crystallization from petroleum ether gave pure 2-hydroxy-2-methylvaleric acid (3 g, 53% yield, mp $52-53^{\circ}$, lit. 54°): ir (CCl_4) 1732 (C=O), 3550 cm^{-1} (OH); NMR (Me_4Si , CCl_4) δ 1.43 (s, α Me), 7.23 (br s, OH).

Anal. Calcd for $\text{C}_6\text{H}_{12}\text{O}_3$: C, 54.53; H, 9.15. Found: C, 54.54; H, 9.25.

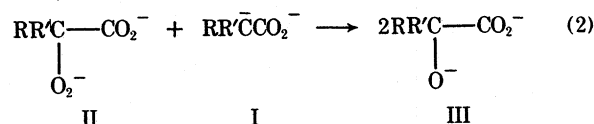
Results and Discussion

2-Hydroperoxy Acids and Esters. The quantitative generation of enolate anions from acids^{8b} and esters^{15,16}

prior to oxidation is essential for the optimization of oxygenated products (Tables I and II). The primary oxygenation reaction that is formulated in eq 1 for conversion of



enolate dianions I (R, R' = H or alkyl) to 2-peroxy carboxylate dianions II is accompanied by carbanion reduction of II leading to 2-hydroxycarboxylic acids (anion III, eq 2).



The competitive reduction was minimized by adaptation of Walling's¹⁷ technique of inverse addition of carbanions to oxygen-saturated ether.

2-Hydroperoxy esters were similarly prepared from ester enolates. Direct oxygenation was preferred to inverse addition, since warming of enolate on transfer gave significant amounts of Claisen condensation product VI (eq 3 and

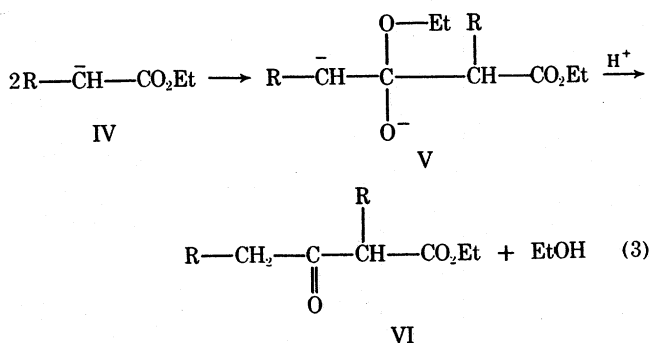
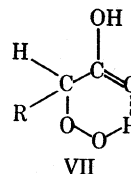


Table II). Methyl esters were also conveniently obtained for analytical purposes by reaction of hydroperoxy acid with diazomethane which specifically methylated the carboxylic acid group. The reaction's specificity was confirmed by iodometric and elemental analysis and by spectral (ir and NMR) comparisons of the products with preparations from ester enolate anions. Since simple hydroperoxides are alkylated by diazoalkanes,¹⁸ the diminished reactivity of hydroperoxide in α -hydroperoxy acids may be attributed to intramolecular hydrogen bonding as depicted by structure VII.



The majority of 2-hydroperoxycarboxylic acids prepared and listed in Table I were stable and easily separated from 2-hydroxycarboxylic acids by silicic acid chromatography. 2-Heptyl-2-hydroperoxydecanoic acid was least stable and was recoverable only in impure form. A solution of the peroxide completely decomposed overnight to a mixture of heptyl octyl ketone and 2-hydroxy-2-heptyldecanoic acid whereas its methyl ester was stable at room temperature. The araliphatic derivative, 2-hydroperoxyphenylacetic acid, which was not isolable gave benzaldehyde (60%), 2-hydroxyphenylacetic acid (25%), and minor amounts of benzoic acid as products. Since carbinol is derived by carbanion reduction of hydroperoxide, 2-hydroxyphenylacetic acid provides evidence of the initial hydroperoxide formation. Benzaldehyde was, therefore, assumed to arise by decarboxylative dehydration of the intermediate 2-hydroperoxyphenylacetic acid⁹ and benzoic acid by oxidation of benzaldehyde.

Unsaturated 2-hydroperoxycarboxylic acids (Table I) were surprisingly unstable in comparison with saturated members. The long-chain *trans* isomer, 2-hydroperoxy-elaidic acid, was more stable than the oleic isomer but stability of the latter was enhanced by esterification. The cause of a long-range interaction inducing destabilization of the hydroperoxide 7-8 carbon atoms distant from the olefinic site remains unanswered. 2-Hydroperoxy-*trans*-3-hexenoic acid and the methyl ester were both unstable. This instability may be related to the physical state of the unsaturates, i.e., the liquids may be more unstable than the solids which are more often the saturated analogs. Rapid decomposition is also observed for the saturated branched-chain 2-hydroperoxy-2-heptyldecanoic acid (a liquid), whereas the solid branched-chain compounds are relatively stable for long periods.

The oxygenation of *trans*-3-hexanoate dianion followed an unexpected reaction pathway. Selective α -oxygenation was anticipated on the basis of our previous studies of substitutions of 2- and 3-hexenoate dianions with alkyl halide¹⁹ and cyclohexanone,²⁰ which had established the near-exclusive formation of 2-substituted 3-hexenoic acids. The initially formed unstable hydroperoxide derivative decomposed to a mixture of 2-hydroxy-3-hexenoic acid (α -substitution), 4-hydroxy-2-hexenoic acid (γ -substitution) and 4-oxo-2-hexenoic acid (γ -substitution). While α -oxygenation predominated, γ -oxygenation was substantial and produced products in a proportion dependent on temperature, i.e., the α/γ ratio was about 3:1 at -75° and 9:1 at 25° .²¹ The relatively high proportion of γ -oxygenated product was at variance with our former conclusions of selective α -substitution in hexenoic acids.^{19,20} The apparent contradiction in these results has, therefore, prompted further inquiry into the oxygen substitution pattern which is currently under study.

Structure and Decomposition. Infrared and NMR spectral data provide evidence for free and hydrogen-bonded structures of 2-hydroperoxycarboxylic acids and esters. The infrared absorptions of methyl 2-hydroperoxytetradecanoate in CCl_4 showed marked changes in $\nu(\text{OH})$ with concentration. At high concentration ($7.3 \times 10^{-1} M$) a broad absorption at 3425 cm^{-1} , presumably due to intermolecular and intramolecular hydrogen-bonded OOH, is observed. Upon dilution, a movement to higher frequency and narrowing of this band is apparent. At tenfold dilution, the OH band has shifted to 3480 cm^{-1} approaching the region associated with free OH absorption. In branched-chain 2-hydroperoxy esters such as methyl 2-ethyl-2-hydroperoxytetradecanoate, different spectral absorption characteristics with dilution were noted. At high concentration ($6.6 \times 10^{-1} M$) absorption of predominantly hydrogen-

Table III
Chemical Shifts of Acidic Protons
and pK Values of Peroxy Compounds

Compd	Chemical shift, ppm ^a	pK _a
Peroxy-carboxylic acids ^b	10.9–11.8 ^c	7–8
Straight-chain	9.8	
2-hydroperoxy esters		
Branched-chain	8.9–9.0	
2-hydroperoxy esters		
Hydroperoxides ^b	7.6–9.2	11.6–12.8

^a Downfield from Me_4Si as internal reference in 10% CCl_4 solutions. ^b L. S. Silbert in "Organic Peroxides", Vol. II, D. Swern, Ed., Wiley, New York, N.Y., 1971, p 702. ^c Spectra obtained in CDCl_3 .

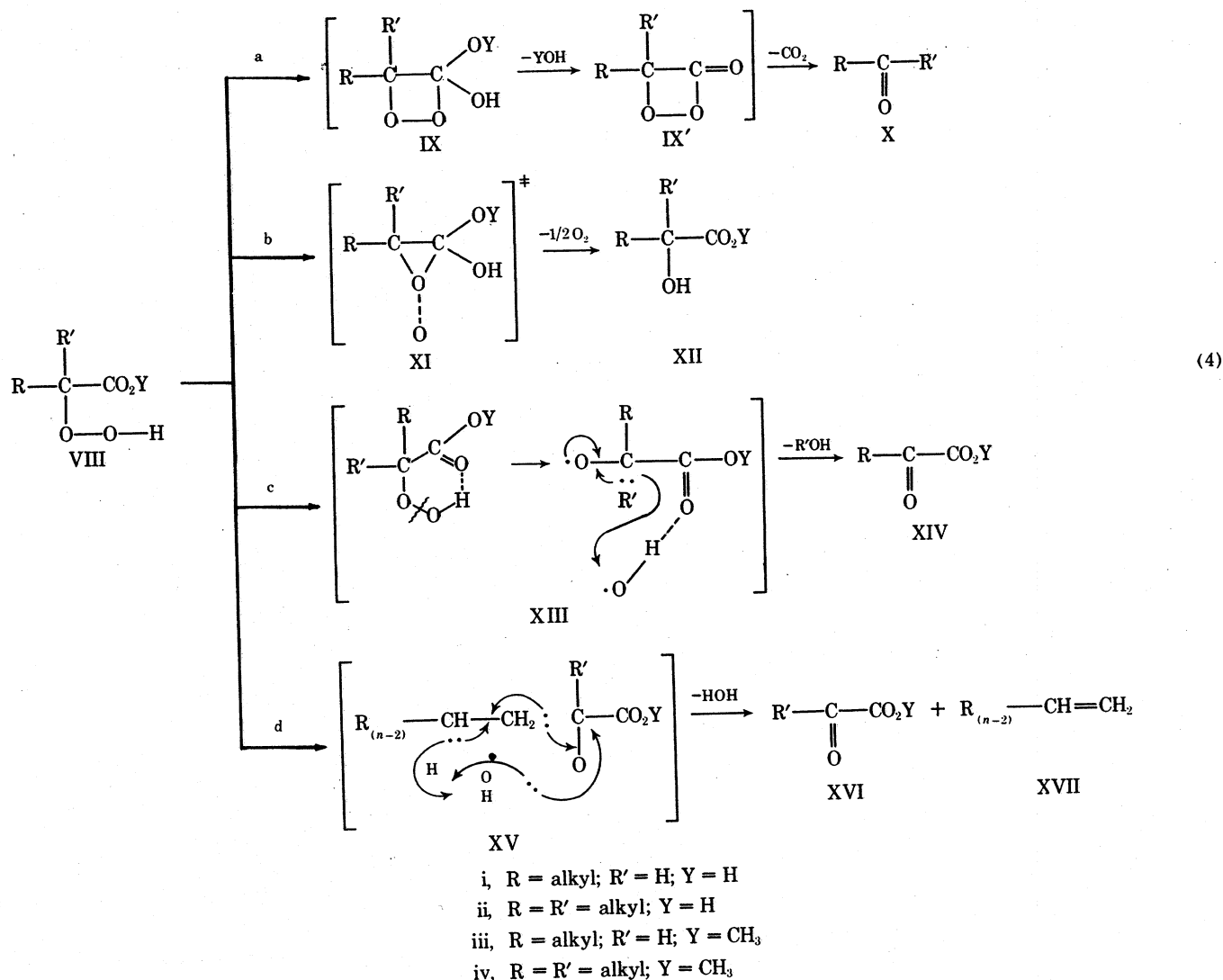
bonded OH was observed at 3450 cm^{-1} . However, unlike the straight-chain analog above, the shift of the major band was small within tenfold dilution. In addition, a new relatively sharp shoulder indicative of free OH was observed at 3520 cm^{-1} . Similar absorption characteristics for the closely related α -hydroperoxy ketones have been reported by Richardson and Steed.²² Their assignments suggest that the narrow, high-frequency band (3546 cm^{-1}) is due to a free hydroperoxide species.

The position of the proton shifts of free OOH protons of straight-chain 2-hydroperoxy esters suggests their relative acidity to be intermediate to alkylhydroperoxides and peroxy-carboxylic acids (Table III). Both increased acidity and lowered chemical shift are attributable to facile intramolecular bonding with the adjacent carbomethoxy carbonyl as depicted by structure VII. Branched-chain 2-hydroperoxy esters exhibit free OOH resonances at slightly higher fields relative to the straight-chain species because of the electron-donating effects of the 2-alkyl substituent (Table III).

It is well known that the free OH proton resonances of hydroperoxides shift upfield with dilution.²³ The same phenomenon is observed for 2-hydroperoxy ester OOH resonances. Sixfold dilution (CCl_4) from 0.585 to 0.098 *M* of methyl 2-hydroperoxytetradecanoate produced a moderate upfield shift of 0.37 ppm for the OOH resonance. Although this dilution shift is small relative to those observed for alcohols, it nevertheless demonstrates the presence of distinct hydrogen-bonded species.

The hydroperoxycarboxylic acids and esters decomposed primarily to carbonyl and carbinol products (eq 4a,b). Straight-chain hydroperoxy acids (VIIIi) such as 2-hydroperoxyoctanoic acid decomposed in benzene at $70\text{--}75^\circ$ to aldehyde (Xi, 44% heptaldehyde) and hydroxy acids (XIIIi, 56% 2-hydroxyoctanoic) and α -branched chain hydroperoxy acids (VIIIii) decomposed in aromatic solvents (benzene, chlorobenzene, xylene)²⁴ to dialkyl ketones (Xii, 85%) and to 2-hydroxy acids (XIIIii, 15%).

The more stable methyl esters were subject to decomposition at higher temperatures. Decomposition and analysis were conveniently carried out by direct injection into a gas chromatograph. The methyl esters of unbranched 2-hydroperoxy acids (VIIIiii, eq 4b,c) decomposed to only two products, methyl α -keto ester (XIViii) and methyl α -hydroxy ester (XIIIiii). The structures of XIIIiii and XIViii were substantiated by comparison of their spectra (ir, NMR, mass spectra) with authentic materials. By maintaining constant instrumental conditions, the products were obtained in the constant ratio of 85:15, though the ratio varied with changes in injection port temperature. The simplicity of the technique provided a rapid method of analysis that complemented iodometric analyses. The methyl esters of 2-hydroperoxy branched-chain acids de-



composed to a more complex mixture of products. In illustration of the products and percentages obtained, methyl 2-methyl-2-hydroperoxydecanoate (VIIIiv) gave rise to four products: methyl 2-methyl-2-hydroxydecanoate (XIIiv, 53%), methyl octyl ketone (Xiv, 19%), methyl 2-ketopropionate (XVIiv, 13%), and 1-octene (XVIIiv, 13%) (eq 4a,b,d).

On the basis of limited evidence, a generalized but speculative scheme to account for products of decomposition is proposed below. Either of the basic oxygen atoms in the hydroperoxide group may cyclize with the polarizable carbonyl in formation of reactive intermediates or transition states. Cyclization with the terminal peroxide oxygen and loss of YOH (CH₃OH or H₂O) leads to an α -peroxylactone IX'. This intermediate, which was recently prepared by Adams and Liu,⁵ decomposes to ketone X (or aldehyde for unbranched hydroperoxy acids) with loss of carbon dioxide. α -Hydroxy acids or esters may be derived by cyclization with the penultimate oxygen to an assumed transition state XI of α -lactone hydrate or hemiacetal with concerted loss of nascent oxygen. α -Keto esters XIV arising from unbranched esters cannot originate from a peroxylactone intermediate. A probable mechanism may involve homolytic rupture of the hydroperoxide to hydroxyl radical that is intramolecularly maintained by hydrogen bonding (XIII) to abstract α hydrogen. Finally, decomposition of α -branched esters yielded two additional products, α -keto ester XVI and olefin XVII, in equivalent amounts. The α -keto ester

cannot arise by any of the forestated pathways such as c since there is no α hydrogen available for abstraction. Thus XVI must be produced simultaneously with olefin via pathway d, which involves intramolecular β -hydrogen abstraction by hydroxyl radical and electronic rearrangement to products as depicted by structure XV.

Attempts to measure the kinetics of decomposition of the hydroperoxy acids were fraught with difficulties that were incompletely resolved. The α -hydroperoxy acids are sensitive to catalytic decomposition initiated at wall surfaces of Pyrex NMR tubes, Pyrex volumetric flasks, and Teflon bottles. Inconsistent decomposition rates were obtained in NMR tubes that were either pretreated by potassium hydroxide solution or used without pretreatment.

In illustration of a decomposition in deuterated benzene solutions in the NMR spectrometer, 2-hydroperoxyoctanoic acid decomposed completely to aldehyde and α -hydroxy acid in untreated tubes but no decomposition ensued in 10 hr in treated tubes; 2-methyl-2-hydroperoxydecanoic acid decomposed solely to ketone by a zero-order reaction (ketone formed vs. time) to the extent of 50% decomposition in 5 hr in untreated tubes and in 32 hr in base-washed tubes. These results suggested the intervention of acid catalysis at the wall surface of untreated tubes. The effects of the type and concentration of acid (acetic, trichloroacetic, and ethanesulfonic acid), iron catalyst, and container material (glass, Teflon) on the decompositions were therefore examined.

Table IV
Preparation of 2-Hydroxyalkanoic Acids

Starting acid	Temp, °C	% 2-OOH ^a	% 2-OH ^b	% yield ^c	Mp, °C	Registry no.
Octanoic	-10	17	65			617-73-2
Octanoic	25	2	94	63	69-70 (69.5) ^d	
Tetra-decanoic	40		74	69	82-83 (81.5-82) ^d	2507-55-3
2-Methyl-valeric	-10	39	60			28892-68-4
2-Methyl-valeric	25	12	87	53	52-53 (54-54.5) ^d	

^a Determined by iodometric analysis of crude product. ^b Determined by GLC analysis of esterified crude product. ^c Isolated pure product. ^d Literature values taken from common reference sources.

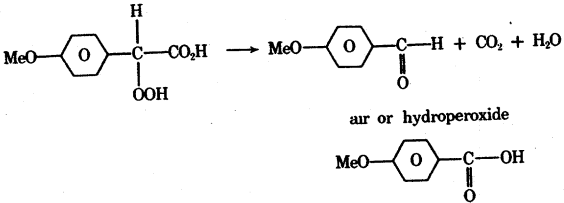
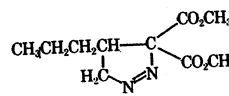
The decompositions carried out under these varied conditions gave irreproducible k values. The first-order kinetic rate constant for 2-hydroperoxy-2-methyltetradecanoic acid decompositions in an untreated Teflon bottle ($5 \times 10^{-2} \text{ hr}^{-1}$ at 75° in chlorobenzene) was 10-20 times larger than values in Teflon bottles preconditioned by peroxide decompositions. Unfortunately, the k values for decompositions carried out in preconditioned bottles varied significantly during successive experiments. Under these conditions, first-order rate constants for 2-hydroperoxytetradecanoic and 2-hydroperoxy-2-alkyltetradecanoic acids (alkyl = Me, Et, Pr) ranged within 10^{-1} to 10^{-2} hr^{-1} but confidence in the accuracy of individual values is low owing to the forestated inconsistencies in reproducibility. The effect of larger alkyl substituents was demonstrated by the greater instability of 2-hydroperoxy-2-heptyldecanoic acid which suggested that higher rates of decomposition were induced by longer α -branched chains. However, since this compound is a liquid, it is unclear whether its physical state is responsible for its enhanced instability. The qualitative kinetic evidence has, nevertheless, implicated structural effects on the stability of solid saturated α -hydroperoxy acids that may be tentatively summarized in the order unbranched > small R α -branched > large R α -branched.

2-Hydroxy Acids. Direct passage of oxygen into anion solutions allows for competitive reduction of hydroperoxide anion II through reaction with excess anion I in formation of alkoxide III (eq 2). The reduction step formulated in eq 2 proceeds rapidly at room temperature so that only small amounts of hydroperoxide survive as the contaminant in α -hydroxy acid preparations. The results of oxygenations recorded in Table IV illustrate the lower degree of hydroperoxide formation at 25° relative to oxygenations at -10° and the associated increase in hydroxy acid formation. Since this method works well for both straight- and branched-chain acids, it is superior to previous methods for the preparation of 2-hydroxy acids.¹⁰⁻¹²

While the present study of direct oxidation was in progress, a similar method of preparation of 2-hydroxy acids was reported by Moersch and Zwiesler.⁹ Aeration of the appropriate dianion solution by their procedure produced 2-hydroxy acids in 14-18 hr. Our method employing pure oxygen reduced reaction times to 30 min with high conversions of carboxylic acids to α -hydroxy acids.

Registry No.—Methyl 2-hydroperoxytetradecanoate, 56363-70-3; methyl 2-hydroperoxy-2-methyltetradecanoate, 56363-71-4; methyl 2-hydroperoxyelaidate, 56363-72-5.

References and Notes

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 - (21) Carbonation at -75° gave the anticipated α -substituted product $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}(\text{CO}_2\text{H})_2$. Although α -substitution was correspondingly predominant at 25° , the acidity of malonate C-H rendered the allylic moiety labile to isomerization which at the higher temperature in basic media led to extensive isomerization to the ethylidene derivative $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}=\text{C}(\text{CO}_2\text{H})_2$. Reaction of the latter with diazomethane for GLC analysis gave the corresponding pyrazoline which pyrolyzed in the heated chamber with formation of two alkylated products,
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- (22) $\text{CH}_3(\text{CH}_2)_2\text{C}(\text{CH}_3)=\text{C}(\text{CO}_2\text{CH}_3)_2$ and $\text{CH}_3(\text{CH}_2)_3\text{CH}=\text{C}(\text{CO}_2\text{CH}_3)_2$, and a trace of a third of presumed cyclopropane structure.
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